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XMM-Newton observations of MSH14-6*3* (RCW 86)

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Abstract. We present an analysis of the X-ray emission of the supernova remnant MSH14-6*3*, which was partially covered by three observations with XMM-Newton. The detection of Fe K emission at 6.4 keV, and the lack of spatial correlation between hard X-ray and radio emission is evidence against a dominant X-ray synchrotron component. We argue that the hard X-ray continuum is best explained by non-thermal bremsstrahlung from a supra-thermal tail to an otherwise cool electron gas. The existence of low electron temperatures is supported by low temperatures found in other parts of the remnant, which are as low as 0.2 keV in some regions.

1. Introduction

The X-ray emission from the supernova remnant MSH14-6*3* (RCW 86, G315.2-2.3) is characterized by spatially distinct soft and hard X-ray components (Vink, Kaastra, & Bleeker 1997). The soft X-ray emission has a thermal nature, but the hard X-ray emission shows relatively little line emission, suggesting X-ray synchrotron radiation (Borkowski et al. 2001), similar to SN 1006 (Koyama et al. 1995). Borkowski et al. argue that additional evidence for X-ray synchrotron radiation is the spatial correlation between hard X-ray and radio emission.

A problem is, however, that the hard X-ray emission is accompanied by Fe K line emission at 6.4 keV (Vink et al. 1997). The energy of the line emission indicates that the emission is from underionized iron (Fe XVII or lower), but it also proofs that the line emitting plasma contains electrons with energies in excess of 7.1 keV. These electrons should give rise to bremsstrahlung emission, suggesting that at least part of the hard X-ray continuum is bremsstrahlung.

We present here XMM-Newton data of MSH14-6*3*. XMM-Newton offers a superior sensitivity and spatial resolution (FWHM $\sim 6''$) compared to ASCA. This allows for a better separation of the hard and soft X-ray emitting regions.

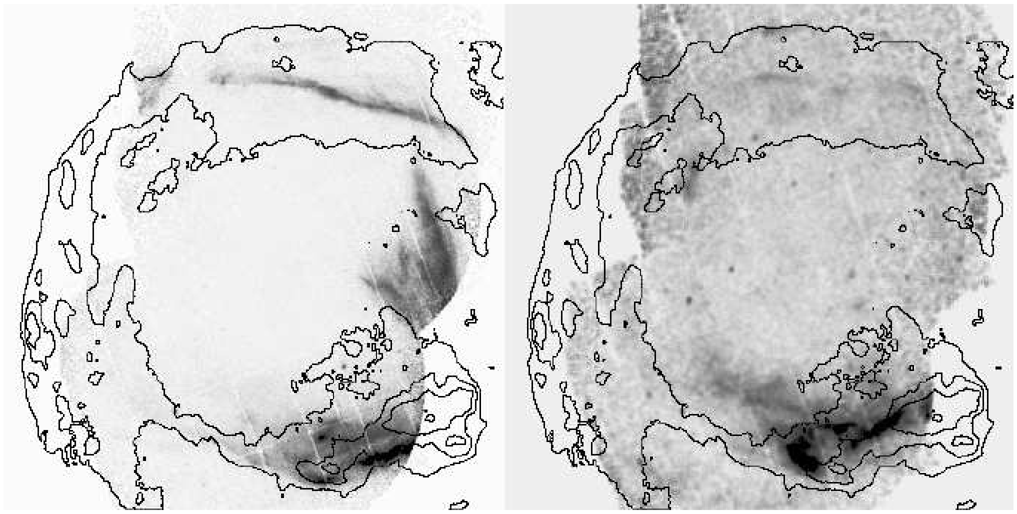

Figure 1. Soft X-ray (0.5-1 keV), left, and hard X-ray (2-7 keV) XMM-Newton mosaics of MSH14-6*3*, combining exposure and effective area corrected data from all three CCD cameras; radio contours (ATCA, Dickel, Strom, & Milne, 2000) are overlayed.

The complete set of observations covers most of the remnant, but here we only discuss data from the southeastern, central and northwestern part, which were observed in August 2000 with exposures of $\sim$ 12 ks to 17 ks. More recent observations of the southwestern part will be presented in a future article.

2. The soft, thermal X-ray emission

The soft X-ray emitting regions have a relatively low ionization characterized by O VII, O VIII, Ne IX and Fe XVII with an interesting variation in the relative importance of O VII emission. The line emission is best illustrated by the spectrum from the northern shell obtained with the reflective grating spectrometer (RGS) (Fig. 2a). The spectrum is dominated by O VII emission, as is also the case for regions north of the shell and the fainter soft X-ray emitting regions in the southeast. Fig. 2b shows the variation in O VII and O VIII emission, as observed by the EPIC PN instrument (Strüder et al. 2001).

The low ionization is likely to be the result of a low electron temperature and a small ionization timescale. Unfortunately, these two plasma properties are not well constraint. For the region with the lowest ionization, a region north of the northern shell, a temperature above 0.5 keV is only possible if the ionization timescale is $\log(n_{\rm e}t) < 9.9$. A lower limit to the temperature can be obtained by fitting a collisional ionization equilibrium (CIE) model, indicating an electron temperature possibly as low as 0.09 keV. The brightest soft X-ray emitting regions in the southeast may have $kT_{\rm e}$= 0.17 keV (CIE).[1]

[1] For the CIE model we used *mekal* (Mewe et al. 1995), for the NEI model we used the model contained in the *SPEX* program which is based on *mekal*.

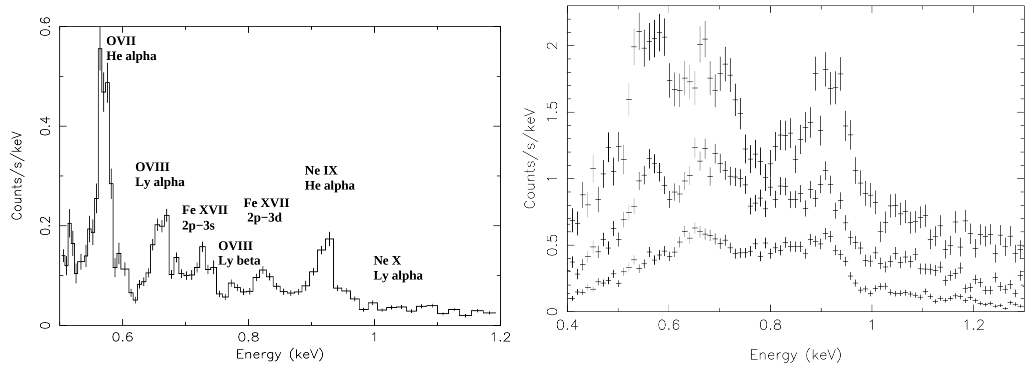

Figure 2. Left: high resolution RGS spectrum from the northwestern shell. Right: EPIC-PN spectra from various regions of the remnant. The top spectrum is from a region north of the northern shell; the other two spectra are from regions in the southeast.

The observed temperature range (0.1 - 0.5 keV) is lower than indicated by the ASCA spectra (which was not very sensitive to O VII emission), but is consistent with the measured width of the Hα and Hβ lines, which, under assumption of full electron-ion equilibration, imply shock velocities of 310 - 605 km/s (Ghavamian et al. 2001).

3. The nature of the hard X-ray emission

If it were not for the presence of the Fe K emission, the most likely mechanism for the X-ray continuum would be synchrotron radiation. The presence of Fe K emission, which is confirmed by the XMM-Newton data suggests, however, that at least part of the hard X-ray emission is bremsstrahlung.

The XMM-Newton data indicates an Fe K equivalent width of ~ 0.25 keV. Modeling bremsstrahlung and Fe K line emission from thermal and non-thermal electron distributions using the well known Lotz formula (e.g. Mewe 1999), we find that for the observed equivalent width and solar abundances, a temperature of at least 3 keV or a electron power law index ≥ -2.5 are required, the latter value is consistent with the observed power law index of -2.7 ± 0.1.

Emission from underionized Fe suggests that other elements may be underionized as well, but are not observed in the spectra as lower Z elements have a smaller probability for a radiative transition after inner shell ionization. Vink et al. (1997) have argued that non-thermal bremsstrahlung may be a more appropriate model than thermal bremsstrahlung, as the cool, thermalized, part of the non-thermal distribution delays the ionization of the plasma. Moreover, the low temperatures and shock velocities from other parts of the remnant are in sharp contrast to the > 3 keV temperatures needed to explain the Fe K emission. Non-thermal distributions have been predicted for heating and acceleration of particles by collisionless shocks (Bykov & Uvarov). There are, however, some problems with this interpretation. For instance, the lack of O VII emission

from the hard X-ray emitting regions require a low temperature and additional non-equilibration ionization effects.

The statistics for the Fe K emission is limited, but its spatial distribution is consistent with that of the hard X-ray continuum, suggesting the two are related. This is hard to reconcile with a synchrotron model, for which the continuum is caused by electrons with energies in excess of 10 TeV, and the line emission is caused by electrons with energies lower by 9 orders of magnitude.

With the better spatial resolution and sensitivity of XMM-Newton it is now also clear that, even in a qualitative sense, there is not a good correlation between hard X-ray and radio synchrotron emission, which was one of the principle arguments for synchrotron emission put forward by Borkowski et al. (2001), based on the poor resolution ASCA hard X-ray maps. Fig. 1 shows this in particular for the southeastern region, where the hard X-ray emission bends towards the center, where there is no obvious radio counterpart.

4. Concluding remarks

Based on XMM-Newton observations we have argued that the hard X-ray emission from MSH14-6*3* is (non-thermal) bremsstrahlung rather than synchrotron emission. The mysterious X-ray emission may play a key role in studying non-thermal processes associated with collisionless shock heating and acceleration. To understand the nature of the hard X-ray emission, detailed maps of the continuum and Fe K emission are needed. A close correlation between the two would indicate a bremsstrahlung nature. A lack of correlation would indicate that the hard X-ray emission comes from two distinct components: ultrarelativistic electrons and a hot plasma. This issue can therefore be resolved by a deep XMM-Newton observation.

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